Stars in Her Eyes

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Body

When she became an astronomer,Sallie Baliunas never thought she'd be posing for magazine photos. But her life as a scientist hasn't been a matter of pure research. In her quest to study the stars, she has found herself drawn into the world of entrepreneurship and public policy.

An astronomer at the Harvard-Smithsonian Center for Astrophysics in Massachusetts, Baliunas is also the deputy director of the Mount Wilson Institute in the San Gabriel Mountains north of Pasadena, California. She spends about a week a month on the West Coast, using Mount Wilson's historic 100-inch telescope to study "sun-like stars." Baliunas came to the observatory as a graduate student in 1977. On her very first night, a lightning bolt struck a tree outside the dining room. "All the windows in the building were shattered from the shock wave of the tree disintegrating," she recalls. "This was an omen whose meaning was not clear until years later."

The observatory where modern astronomy was born would go through similar shocks in the years to come, as its owners turned their attention elsewhere. But for the dedication of a handful of technical staffers and astronomers, Baliunas among them, Mount Wilson would have been essentially abandoned. Instead, the observatory has not only a new lease on life but some of the best observational equipment in the world. The reborn facility is demonstrating how private funding and advanced technology can nurture innovative science.

Baliunas's own work benefited from Mount Wilson's years of neglect. Telescope time is rare, and few astronomers have the luxury of studying the same stars night after night, year after year. She's the first to admit that her research "could only have been done at an essentially `abandoned' facility, where the competition for telescope time had disappeared." Baliunas is returning the favor, working without pay to raise funds, improve equipment, and manage the operations so such long-term research can continue. She never expected to be a manager but, she says, "The choice seemed clear: either grow the observatory or lose the research program."

In between observing and management, Baliunas can also be found testifying before congressional committees and giving papers at conferences on global climate change--a subject she was drawn to by her research on the sun's fluctuating magnetic field. She is a leading greenhouse skeptic. How, she wondered, could climate models be so specific when we hardly understand the sun or its effect on the earth? Baliunas talked about this and other questions with REASON Editor Virginia Postrel and her husband, Steven Postrel, an economist who teaches business strategy at U.C.-Irvine, under the Mount Wilson dome in late June.

Reason: What do you study?

Sallie Baliunas: I'm interested in why the sun has a regular cycle of magnetism. There's a clock, so to speak. Sunspots come and go every 11 years, and the sun's energy output changes in step with those changes in magnetism. The sun also changes on longer time scales. That has an influence on the earth's environment. So the question is, Why does the sun do that? There is no good basic theory that says why the sun would have a magnetic clock.

Reason: So you look at other stars to try to figure out what's going on with the sun?

Baliunas: Right. Here's an analogy. You're an extraterrestrial and you come to Earth, and you have 24 hours and you want to study the life cycle of a human. You can do one of two things. You can sit and follow one human for 24 hours and watch tiny microscopic changes in that human, or you can gather together a whole town and take information and look at the commonality. You can say, here's an infant and he needs to be taken care of, and here's a kid, and here's a young adult, and put together a picture of the human life span that way. I look at what I call "sun-like stars" at different phases of long-term evolution. It's a great deal quicker than waiting around for the sun to do something.

Reason: Have you gotten any interesting results?

Baliunas: My mentor here--who is buried outside the dome, Olin Wilson--asked the question, Is the sun's 11-year cycle common on other stars, or is it something peculiar about the sun? He began a program here at the telescope in 1966 to follow 100 stars, month after month, year after year. When he retired, I came aboard, and now we have over three decades of records. We see at first glance, what the sun does is not unique. It's a universal trait.

Reason: Eleven years?

Baliunas: Eleven years, on average, if the stars are as old as the sun is. Age seems to make a big difference. When the sun was younger and life was forming on Earth--the sun was about a billion years old, about 3.5 billion years ago--the sun was spinning several times faster than today. That meant that the dynamo that powers the surface magnetism was working much more efficiently, and so the magnetism was much higher. There were more sunspots, there were more high-energy particles, there was more variability of ultraviolet and X-rays.

Reason: How would that affect conditions on the earth?

Baliunas: In several ways. One way is, with that higher amount of activity, there's much more X-ray and ultraviolet flux. The X-ray flux would be about 100 times larger than today. That energy certainly has biological effects--effects on DNA; it can even kill cells. So the environment was much more dangerous to life than today. The ultraviolet fluxes would also be larger, maybe 10 times larger. In addition, the changes over time scales of years or so would also be much larger. So not only are they at a higher sustained level, but they vary, and the variations are larger. The total energy of the sun would have been varying by several percent over a time scale of a few years, during the sunspot cycle. That would play havoc with the climate.

Reason: You've been writing some papers suggesting that terrestrial climate today may be affected by solar variations. In fact you've suggested that some of the warming that people have attributed to burning fossil fuels may actually be the result of natural fluctuation. How did you get involved in that?

Baliunas: Nearly 15 years ago, I started hearing that there now were models--imulations--of the earth's climate system that could be projected 100 years into the future. I was curious and thought, "Wow, that's a significant leap in meteorology and climatology. I want to learn about that." So I began looking at the models and how they can make predictions so far in advance. I also began to look at climate simulations run on computers and ask the question, What is the natural level of climate change? What is the influence of the sun?

The reason for asking how the sun might influence it is that there is lots of direct evidence that the sun has an impact. For example, the sun changes in its brightness [an average of] every 11 years with the magnetic cycle. We know that from recent satellite measurements. But going back further in time, we know the sun changes every few centuries. During the 17th century, which was an unusually cold period on Earth, the sun had very little magnetic activity for about a century--the Maunder Minimum, coincident with the Little Ice Age.

Reason: What is the Maunder Minimum?

Baliunas: The Maunder Minimum is this episode in the 17th century where the 11-year cycle was suppressed--was very quiet--and the sun dropped to very low levels of magnetism.

Reason: The 11-year cycle disappeared?

Baliunas: Almost. There were certainly long months of time, and even a decade toward the end of the 17th century, when sighting a sunspot was very rare.

Reason: Is there any theory for what caused that?

Baliunas: That's the hot question. We have to explain the 11-year cycle in the first place. There's a crude picture that says we know the sun's magnetism changes with time because of the way the sun spins and the way the outer layer rolls with convection. Beyond that, it's not a good theory. Making an 11-year repeating cycle is difficult in most theories. Making it disappear every few centuries is even more difficult.

Reason: How do you know magnetic records of the sun from the 17th century?

Baliunas: The records of sunspots go back to 1609, to Galileo's day, and that's almost long enough to see this episode. But we have some unbiased records: The sun has a wind that carries the magnetic field toward the earth and acts as a shield. There's a rain of cosmic rays coming from deep space. When the sun's magnetic field is strong, these cosmic rays tend to be deflected. When the magnetic field is weak, these cosmic rays penetrate the upper atmosphere of the earth. When the cosmic rays come in, they make radiocarbon in the upper atmosphere, and that carbon-14 ends up in carbon dioxide molecules. It's breathed in by a tree and put in its tree ring, so the amount of carbon-14 over time in tree rings tells you what the sun has been doing in the past. Those records trace the sun back about 10,000 years. So we know the ups and downs of the sun's magnetism for the last 10,000 years or so.

After looking at this, I began to ask, How well do the climate simulations handle this relatively new knowledge about the sun? And the answer is, not very well. We don't know the mechanism for change in the sun very well. We don't know the response of the earth to such changes. So I thought, How do you make predictions 100 years in the future if you don't even know what all the sources of change are?

Reason: If the magnetic activity on the sun is changing, what mechanisms are there that might affect the earth's climate?

Baliunas: It depends what time scale one is talking about. The sun brightens and fades over the sunspot cycle, the 11-year cycle. But also the intensity of the 11-year cycles has been building over the centuries.

Reason: What do you mean by "intensity"?

Baliunas: Looking back several hundred years, the sun's magnetism is at an all-time high. The last four peaks have been quite high.

Reason: Do these fluctuations produce a big effect?

Baliunas: It's relatively small from cycle to cycle, but we estimate that from the 17th century to now it could have been four or five tenths of a percent of the sun's energy output. Run that through a climate model, and that's enough to explain the temperature change.

Reason: Using the current models...

Baliunas: Using the current models...

Reason: Which you're not sure are right anyway...

Baliunas: Nobody's sure--all models have similar problems.

We're saying [with] a few tenths percent change, which we don't think is unreasonable for the sun, you can explain everything. Now that's not the only mechanism. That's the first one, which one might think of as brightness change. There's some new work coming out of Europe on clouds. The amount of cloud coverage on the earth is changing by a few percent every 11 years--it's anti-phased with the cycle. The latest idea is that it's the sun modulating the cosmic rays that are coming in making nuclei of clouds.

So after looking at all these vast unknowns, I then saw the key problem for the greenhouse extremists. We always read about how the temperature has warmed about a degree Fahrenheit--a half degree centigrade--in the last 100 years. But if you look at the temperature records, it's quite clear: All the warming occurs early in the century. But most of the greenhouse gases are put in the atmosphere after World War II, in the last 50 years. So they can't cause most of the warming of the last 100 years. Something else had to. The sun's changes fit that very well. That just may be a coincidence, but that's what we're pursuing.

Reason: What has the sun's effect since 1940 been?

Baliunas: That's a harder question because we consider changes of the sun on time scales of several decades or more. So asking me what has gone on since 1940 is almost at the limit of what I'm looking at. If you want to look back over the last 100, 200, or 300 years, it's a little easier for me to talk about it.

Reason: Would this solar variability research say anything about what would happen if we were really to increase greenhouse gases in the atmosphere a lot?

Baliunas: That experiment has been done. We've increased the amount of greenhouse gases by an equivalent of going halfway to a doubling of carbon dioxide--and doubling is the benchmark that everyone talks about. And then you look at how the earth's temperature has responded, and it has not warmed more than a tenth or two-tenths of a degree. So a simple back-of-the-envelope calculation says a doubling is a few tenths of a degree. That's not significant, because it's not noticeable above the natural background changes.

The real test of this is the last 20 years, with very precise satellite measures of the earth's temperature made globally. The global average temperature of the atmosphere, just above the surface of the earth, has not warmed at all. There's been no warming trend in the past 20 years, and the models all say that there should have been a warming of several tenths of a degree centigrade in that time.

Reason: I've seen flat denials of this by people who claim that the satellite data are either inaccurate or who say they don't care about the air up there, they care about the air down here.

Baliunas: It's true that people live at the surface and not where satellites measure, which is a few kilometers above the surface. But the models make predictions at that layer of the atmosphere, and most of the models make a prediction that that layer should be warming more than the surface, so in fact it's a good test of the models. The satellite data make measurements essentially globally, unlike the surface data, which are very, very irregularly sampled and spaced and have significant systematic errors.

Reason: Where do those systematic errors come from?

Baliunas: There are systematic errors arising, first of all, because of coverage. There is very little coverage of the polar regions of the earth and there's little coverage of the southern hemisphere oceans. People don't live there; there are no thermometers there. But the satellites measure these areas dutifully. Systematic errors also come from the urban heat island effect, which says that as cities have grown--buildings, concrete, pavement, tree clearing--they have warmed that environment. So you can look at the population growth in a city and you can look at its temperature just going hand in hand.

Reason: Critics of the satellite data have argued that you get different results at different altitudes that satellites do reach.

Baliunas: That is true.

Reason: And the atmosphere has warmed at certain levels.

Baliunas: No. There's been no warming in the satellite data. There's been a cooling in the lower stratosphere, and no warming in the lower troposphere. And at the surface, I should mention that the continental U.S. has very good measurements over the last 100 years and there's been no net warming there either.

Reason: How does this fit in with your solar explanations?

Baliunas: We're trying to subtract the sun's influence [from climate fluctuations caused by other sources]. The sun is particularly good at explaining this early 20th-century warming, which can't have been caused by the greenhouse gases. If we had a good prediction for what the sun would do next, given the past calibrations that we've done, we then could make a prediction. But we're not at the point where we can predict what the sun will do 50 years from now.

Reason: There was an International Panel on Climate Change, whose results have been widely disseminated. What do you think about the IPCC report?

Baliunas: The IPCC report actually is very careful to say that the models have not been validated. That tells you that you can't make a prediction with them. The executive summary says that there's a discernible human influence, but the information in the chapter on which that conclusion was based has been overturned by the scientific process. The report is obsolete.

Reason: What overturned it?

Baliunas: The executive summary's conclusion was based on the results of new climate simulations that made predictions both in three dimensions and time. That's the way to go: Global warming won't be uniform over the globe--certain areas or different levels of the atmosphere will warm more than others. So you look at the regions that are supposed to warm first--for example, the Arctic or, in the case of that report, a region of the lower atmosphere over the southern hemisphere oceans. And in the report, it was claimed that there was good agreement between the theory and the observations. But when that underlying paper was published, it was very quickly overturned by a longer stretch of data.

Reason: By whom?

Baliunas: One paper is by Pat Michaels and Chip Knappenberger. That was published in *Nature*.

There had been a short uptick in the temperature of that region, but when looking at a longer temperature record that was both earlier and later, it was seen that that uptick was just part of a long-term null trend. So the models had predicted wrongly. There had been no increase in that area.

Reason: The idea of looking for places where the models make strong predictions is that if it's right anywhere it should be there?

Baliunas: It should be right where the warming is felt first--for example, the polar regions, the Arctic. In the last 50 years, the Arctic has cooled. And the models say it should be warming profoundly. Then the area over the southern hemisphere oceans should be warming, but it has not been warming either.

Reason: There's a particularly compelling figure you've used in your publications, which is a graph of North American land temperature data vs. the magnetic activity of the sun, with multiple turning points that are coincident. [See graph.] First a technical question: What are the units for the magnetic activity?

Baliunas: This is the length of the sunspot cycle. The cycle averages 11 years or, if you count polarity, 22 years. But the cycle can be short, say, eight years, or it can be longer, say, 12, 15 years. So you look at the length of the cycle and plot that to see the relation.

Reason: If the cycle is short, what does that mean?

Baliunas: If the cycle is short, the sun's magnetism is much more intense, and that leads you to the expectation that the sun's brightness would have been greater than if the cycle is long.

Reason: And that correlates beautifully with the turning points...

Baliunas: Right, so the mechanism is that you're still seeing changes in the brightness of the sun, and you're just using as a marker for that something we have a measurement of going back that far, which is the length of the magnetic cycle.

Reason: Given that you've said that the radiant effect, just the pure heat, probably isn't enough to explain it, that's a very striking concordance.

Baliunas: The [radiant] effect is borderline. And it may be that we have the wrong mechanism or that our model has the wrong response, since nobody's model has the right response. Some people have worked on not just looking at the total energy of the sun but, say, a portion of spectrum such as the ultraviolet. A woman in England, Joanna Haigh, would say that the ultraviolet changes in sun, although they seem small, profoundly affect the ozone layer and that those changes in the ozone layer then change the dynamics of the climate system strongly. We may be looking at the right marker but the wrong reason, and that may be why models are still equivocal.

Reason: Mount Wilson was closed for a while...

Baliunas: The 100-inch telescope was closed in 1986. The owners, the Carnegie Institution, had built a large telescope in Chile, and to conserve resources, they wanted to focus on that. By then, a group of us from other universities were already using the other resources on the mountain. I was working my long-term project on the 60-inch telescope; the solar towers were in use. The 100-inch telescope was closed for about eight years while we

raised the money to refurbish the telescope, put in modern computerized pointing, and also redirect where it was going. It wasn't going to do cosmology at the faint edges of the universe--the telescope was now only a modest-sized telescope compared to the 10-meter telescope [at Mauna Kea in Hawaii], and the lights of L.A. were getting too bright. So it took a turning point around 1991.

When George Ellery Hale founded the observatory, he noticed that there was something priceless here: The air is very still, calm, and steady. That means the images from space, celestial objects, as they come down through the atmosphere are least disturbed. We have clarity here that is unmatched by any site in North America, and it's on par with the best sites in the world like Chile and Hawaii. It's a little more convenient being here than at, say, 14,000 feet in Hawaii. So that still air, which astronomers call the "seeing," and the development of technology, opened up some new areas.

We now do high-resolution astronomy. This 80-year-old telescope has now been sharpened up so it takes out the blurring effect of the earth's atmosphere, and it sees images as sharp as if it were out in space. That took about $3 million of mostly private money and some special high-tech equipment developed mostly by the Defense Department during the Strategic Defense Initiative days.

Reason: When did that "adaptive optics" system go in?

Baliunas: This became operational in late 1995.

Reason: Have people using it made any noteworthy discoveries?

Baliunas: We've got the first map of the surface of the asteroid Juno, for example. This is one of these large asteroids very similar to the junk out of which the earth was made. But unlike the earth, which has been processing everything with plate tectonics and its ocean and atmosphere, this asteroid sits out in space virtually untouched in 4 billion years. So you're looking at the primordial state of what made the earth. We're looking at the mineralogy of that.

We're also looking at the volcanos on one of the satellites of Jupiter, which blow up because it's in such proximity to Jupiter. The gravitational pull of Jupiter makes a liquid core in that little satellite.

We're looking at other stars, how stars form, what kind of dust and debris they have around them at various stages. We're taking a census of all the nearby stars and whether or not they're double or triple star systems.

Reason: Is that easier to tell with this technology than with what had gone before?

Baliunas: Yes, because you can look closer in toward the vicinity of the star, and that information had been lost in the blur.

Reason: So the main limit is how far the telescope can see?

Baliunas: Yes, how far, but we can see detail lost by bigger telescopes.

Reason: Why is that?

Baliunas: Because the atmosphere sets the limit of the detail. When the big telescopes get this kind of technology going they will start retrieving it, but right now we're one of the very few that can do this.

Reason: Is the technology making astronomy significantly less expensive to do?

Baliunas: You get images as sharp as if the telescope were in space, for a capital cost of $3 million for the new equipment and the retrofits--compared to the space program. A launch of the Shuttle is half a billion dollars, and if you settle for a Delta rocket, it's a $100 million dollar launch, plus building space-worthy equipment. So it's extremely cost-effective to do things on the ground when you can. This makes the space instruments more effective, because they focus then on the things that they do best.

Reason: You're about to open something called the CHARA Interferometer. What is an interferometer?

Baliunas: An interferometer is a clever way, a very sneaky way of getting detailed information on objects in space without spending a fortune in building a telescope. The optical interferometer will be six smaller telescopes, each one meter across, spread out over a radius of 1,000 feet. And then the light of each individual telescope is brought together and stacked, so the crests and troughs of the waves of light match up. The computer is very carefully measuring the distance to each telescope, which changes subtly. When you do that with these smaller, inexpensive telescopes you get the equivalent detail--spatial detail--as if you had a 1,000-foot diameter single telescope.

Reason: What makes that possible?

Baliunas: It's the ability to stack the wavelengths of the light coming to each telescope with a tolerance of one four-millionth of an inch. That requires sophisticated computer control, engineering control, and lasers all working to calculate the distance to stack these beams of light.

Reason: What sort of research are they expecting to do with that?

Baliunas: One of the more interesting things is to try to start looking for planets around other stars--direct sightings.

Reason: What is it about this array that will make that more likely?

Baliunas: The array can see spatial detail much finer than any other optical ground-based or space-based telescope. It can see very close in to the vicinity of these stars.

Reason: So it can see better than the Hubble?

Baliunas: Sharper detail, finer detail. It could see something as small as an astronaut's bootprint on the moon. And that's something like 100 times finer detail than the Hubble can see.

Reason: But it can't see as far?

Baliunas: Not as far. Technology is making niches, as usual, and this is our niche: fine detail, of objects either in our galaxy or nearby galaxies. Whereas Hubble can see to the faint reaches of the far universe.

Reason: What is your operating budget?

Baliunas: To operate the whole facility is about a million dollars a year.

Reason: Where does your money come from?

Baliunas: It's mostly private foundations and generous individuals, primarily in Southern California. Occasionally we have some government grants from the National Science Foundation or NASA to do some specific project, but most of it's been private.

Reason: This reopening was very much a private venture.

Baliunas: Yes, the idea was to keep Mount Wilson as an option in private hands. The national observatories have, as their obligation, to serve the wider [astronomical] community. That's terrific, but it also means that servicing as many users as possible becomes an important focus for them, which means short-term observing. We prefer to serve important projects that can't get done at the other sites. A long-term project--say, my project, which is 32 years in duration--is a different kind of project.

Reason: A lot of people have the idea that because of the capital equipment costs, you can't do good astronomy without government support.

Baliunas: I disagree with that. You can do good astronomy with government support, but you don't need it. The Keck telescope [at Mauna Kea] is an example of something that was privately funded. And in fact, some politicization often comes with government support.

Reason: Can you give me an example?

Baliunas: You have to write proposals to get telescope time [at the national observatories]. You often have to write them a year in advance. The subscription rate is a factor of several to one, overburdening the time. Three-quarters of the proposals have to be thrown away. So if you want to do something, you might have to submit a proposal several years in a row. It might be four or five years before you get it. The demand is so great that sometimes the tendency is to divide up the time in some "equitable" way, so that means you end up with two or three nights. You arrive and it's cloudy. You have to start the process over again next year.

So that's something we wanted to try to provide to the community--another avenue, where if you wanted 100 nights of telescope time, we'd be in a position to be able to work that out.

Reason: I've heard a lot of scientists in different fields complain that government funding is distorting science, distorting the peer review process. What is your take on that?

Baliunas: There is almost a crisis in the number of scientists and the amount of funding available. There's been a population explosion in the number of scientists practicing, and the amount of government resources available has been not in that proportion.

For example, NASA's budget in the Apollo program days was a much higher percent of GNP than it is today. A lot of astronomy funding has historically been a fixed fraction of the NASA budget, so that means that as a percentage of GNP, that number has gone down in real terms, but there are more people competing for those dollars. So now when you do proposals, you don't write an open proposal. You don't say, "I have this great idea," and then write it down. You look to see what targeted program your idea might fit into, and if there's not a targeted program, you go try to lobby for one to be made.

Reason: What is a targeted program?

Baliunas: For example, discovering extrasolar planets is now something very interesting, so NASA has an origins program encompassing that. But before a specific program existed for extrasolar planet studies, such research was difficult to fund. If you're doing something that is radically different, it might not fit into one of the bins. You have to bend your science into one of those bins, or you have to work on getting a new bin accepted.

Some of the targeted areas are so overburdened that nine out of 10 proposals get rejected. I've been on panel reviews where there were many excellent proposals, but you have to make a decision and throw out 90 percent of them because the budgets can't take them all.

Reason: You first came to Mount Wilson because your graduate school adviser told all his students that you should do some observing at the "mecca of modern astronomy." What makes Mount Wilson the mecca?

Baliunas: Mount Wilson is where astronomy took its modern turn. Astronomy used to be, in the 19th century, cataloging--a very personal, artistic journey of looking at the sky. George Ellery Hale, who founded the observatory, changed all that. He thought that there was something to be learned from astronomy other than positions. There was what powered the sun, the changes of the sun, how did they influence the earth, how did life begin here, and what influence does the space environment have on those larger issues? What are the stars? How big is the universe? Where did it come from? Where is it headed to? The idea of the evolution of the physical universe was very important to Hale. He was influenced by Darwin's Origin of Species.

Hale was a brilliant scientist. He worked at Yerkes Observatory in Chicago--he was born in Chicago, went to MIT. He went back to Yerkes and built the largest telescope in the world there at the end of the last century. That was the 40-inch Yerkes Refractor Telescope. He found Chicago not to be the best environment for doing astronomy, because of the high percentage of cloudy nights. He went with a committee on a site-testing tour, and decided that this mountaintop had images through testing telescopes that were the finest of any site that they had ever seen. He decided that this would be a good place to found the observatory.

He packed up the solar telescope and brought it out here in 1904. He took a great risk because at that time he had very little commitment of any funding. But his themes were always, "Make no small plans, dream no small dreams" and "More light." His father was fairly well-off and had given him a 60-inch mirror blank in 1896 as a birthday present. He was again going to build the largest telescope in the world, the 60-inch telescope. It took him 10 years to find a site, and another four years to find the money--much of which he borrowed from his friends, neighbors, and relatives--to finally get the 60-inch telescope opened in 1908.

Reason: How much did that cost?

Baliunas: I know there was a donation of $50,000 for the 100-inch mirror; the 60-inch mirror was $2,000 in 1894 dollars.

Reason: Mount Wilson is at the top of a mountain and even today, it's a bit of a haul up a winding, fairly narrow road. Certainly in 1908 or even 1917, it was worse. How did they build the observatory?

Baliunas: The builders had this vision and just had to overcome terrible conditions. There's a hiking trail that goes up from Sierra Madre--that was the old toll road, a private road in those days--and everything had to be brought up either in your backpack or by mule trains. Everything had to be broken down into small bits and then built in place on the mountain. You see the amount of massive concrete and steel structures. They had to haul everything up, and it took at least a good day to get up the mountain. Even though it was a seven-mile trail, it was very steep. By 1910, there were primitive trucks and the trail had to be widened by human labor, and then things could be brought up that way.

Reason: Who built the observatory--the 100-inch telescope?

Baliunas: They went to a steel company in Chicago, named Morava, for the dome. They built and assembled the steel dome and structure in Chicago, then took it apart and brought it up the mountain. The concrete was put in place by the observatory staff--they had a concrete plant up here. The whole telescope was designed by the observatory staff. The mirror was cast in France, and it was ground to its fine shape down in Pasadena by the observatory staff. The telescope tube--the structure that holds the mirror and moves--was built by the Fore River Shipyards in Massachusetts, which built battleships. The telescope itself weighs 100 tons, the moving part of it--the tube.

Reason: This was all done with private money?

Baliunas: It was all private. By 1908, Hale had convinced a businessman in Los Angeles, John Hooker, to pay for the casting of the 100-inch telescope, and he got Andrew Carnegie to invest in the observatory. This is his third time he built the largest telescope in the world, and the fourth one is the 200-inch at Palomar Mountain.

Reason: You told a story about the Huntington Library in Pasadena that indicated that Hale had a dim view of government control.

Baliunas: He was talking to Henry Huntington, who had this fabulous collection of rare books. Huntington was thinking about what to do with them after his death, and he began thinking of a publicly owned--probably city-owned--library where people could use them. Hale had a view that once you entered the political process, it was a dangerous thing. He suggested to Huntington that instead, why not have a private library, for which they would raise the funds, to be run by scholars who would ensure public access. And that's worked very well to this day.

Reason: He was a little nervous about challenging Huntington--is that because Huntington also supported the observatory?

Baliunas: No, I think he just respected Huntington's desire to do what he wanted with his own property. But Hale did say, "Realizing the menace inherent in political control, I took my life in my hands and wrote him a letter."

Reason: The 100-inch telescope here opened when?

Baliunas: It opened in 1917. And this is where Edwin Hubble made his discoveries of our place in the cosmos.

Reason: Who was Hubble?

Baliunas: Edwin Hubble was an astronomer who came here in 1919 and made modern cosmology. In 1900, no one knew what a galaxy was. It's a term we all use, but it wasn't in use then. The Milky Way, which was thought to be about a 100,000 light-years across, was all there was of the universe. The universe was static, unchanging, eternal--it had always been. And it was finite, something you can grasp. A hundred thousand light years is not so bad for the human mind to wrap around.

Hubble came along, and by 1923 he was interested in something called nebulae, the Latin word for clouds, which were faint, pinwheel smudges that one would see through the telescope. Hubble looked at the Andromeda nebula, which is in the constellation Andromeda, and found a special kind of star. The star changes in brightness rhythmically. By measuring the period, you know the intrinsic brightness of that star. I use this example: When one drives on the road at night and you see the streetlights or the lights of an oncoming car, you automatically think, "I know how bright a streetlight is when it's next to me," or how bright headlights are, so you make a mental calculation as you look at how dim the lights are; you say, "OK, it's far away," or "It's near." The word in astronomy is "standard candle," but I've always found that not to evoke the right image. It's something whose intrinsic brightness you know and by looking at its apparent brightness--because the intensity of light fades with the square of the distance--you can easily calculate the distance.

Hubble saw how faint the star looked on the photo, and then he saw what its real brightness was. So he knew how far away Andromeda was. It is external to our galaxy. It is 2 million light-years away. So now it's not just the Milky Way, but each one of his smudges is a Milky Way, a hundred billion stars, and there's hundreds of billions of these galaxies. So overnight in 1923, he changed the scale of the universe, from being finite to something essentially infinite.

Now by the end of the 1920s he did something else, which is to discover that the universe is not static. He looked at these galaxies again, and he noticed that they had a speed of motion relative to us. The farther away the galaxy is, the faster it's flying away from us. He found the evidence for the expanding universe. This is a notion which is embedded in Einstein's theory of relativity, that there was a beginning to space and time, some 15 billion years ago.

Hubble overturned everything. I call it the last step of the Copernican revolution: The universe is not finite and static. It's infinite and expanding, and what's worse, it had a beginning, which means it's not eternal. And that all happened at the chair here. The little wooden rickety chair.

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